

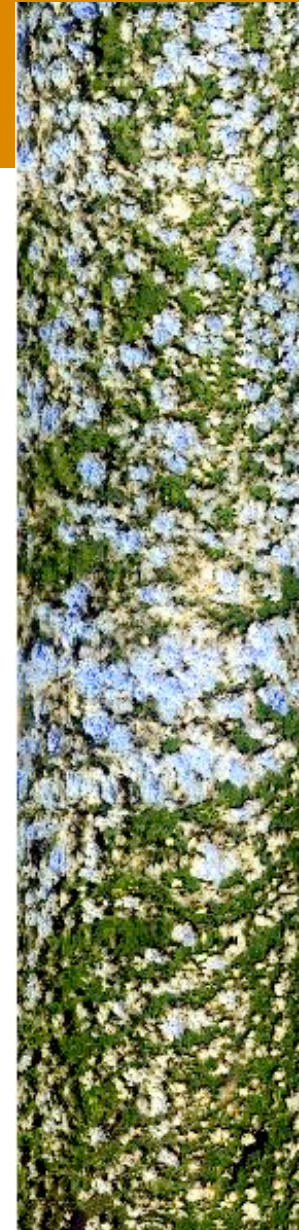
Representation of Shallow Cumuli in Regional Scale Models

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PNNL-SA-68694

Today's Topics

- ▶ Why do we care about shallow Cu?
- ▶ Parameterizations of shallow Cu in regional scale models
- ▶ Sample results for the SGP
 - Data sets and evaluation strategies
- ▶ Road map for future efforts



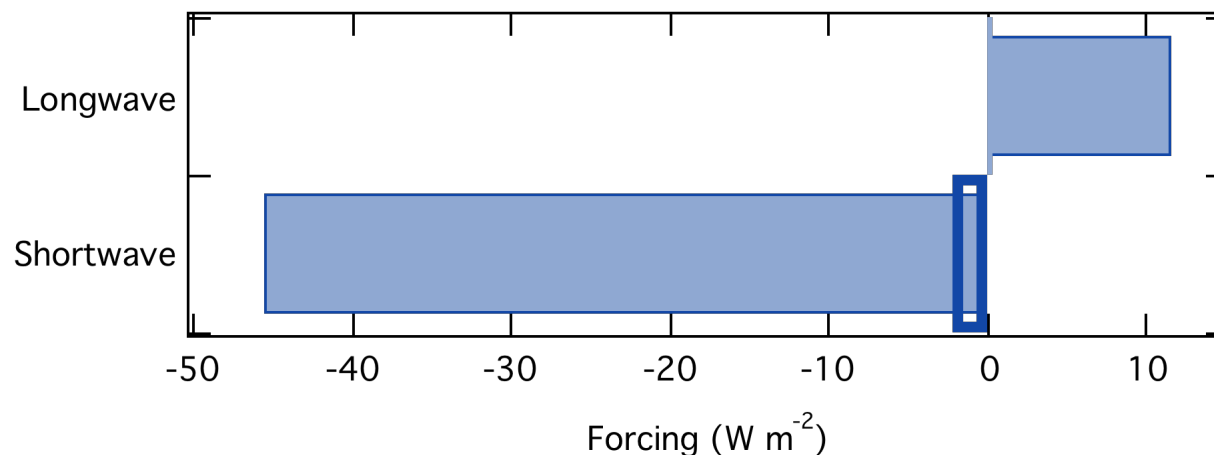
MAS Image captured
during CLASIC

I. Why Study Shallow Clouds?

- ▶ Play an important role in the Earth's radiation budget
 - This role can be underappreciated
- ▶ Transport between convective boundary layer and free troposphere
 - Linkages between surface and clouds (CLASIC)
 - Aerosols can be lofted to higher altitudes
- AGU ■ Cloud-aerosol interactions (CHAPS; Berg et al. 2009—BAMS)
- ▶ Likely to remain sub-grid scale in the future
 - Cloud scale ~1 km
 - “Cloud Resolving Model” ~4 km

I. Why Shallow Clouds: Radiation

- ▶ Recent study (Berg et al. 2009) has looked at the shortwave and longwave cloud forcing
 - Makes use of Chuck Long's VAPs that make estimates of clear-sky shortwave and longwave fluxes



- ▶ Dong et al. (2006) found surface shortwave forcing was -87 W m^{-2}
 - All low-level clouds

II. Parameterization of Shallow Cumuli

- ▶ Two parts to representing convective clouds
 - Do they form (the trigger)?
 - Kain Fritsch uses an ad-hoc temperature perturbation
 - How many form (the closure)?
 - Generally expressed as a mass flux
- ▶ Deep convection closure
 - Based on conditional instability or moisture convergence
- ▶ Shallow convection
 - Based on strength of capping inversion (which can be interpreted different ways: CAPE, CIN)
 - Shallow cumuli are linked to the boundary layer, requiring a *coupling* between turbulence and convective parameterizations


II. Parameterizations

- ▶ A number of new parameterizations for shallow Cu have been introduced and supported by ARM in the past:
 - UW Scheme (Bretherton et. al 2004)
 - ECMWF Scheme (Neggers et al. 2009; ongoing work by M. Ahlgrimm)
 - PNNL (CuP) Scheme (Berg and Stull 2005)
- ▶ Each relates cloud properties to the boundary-layer turbulence, but differences in trigger and closure



II. Parameterizations

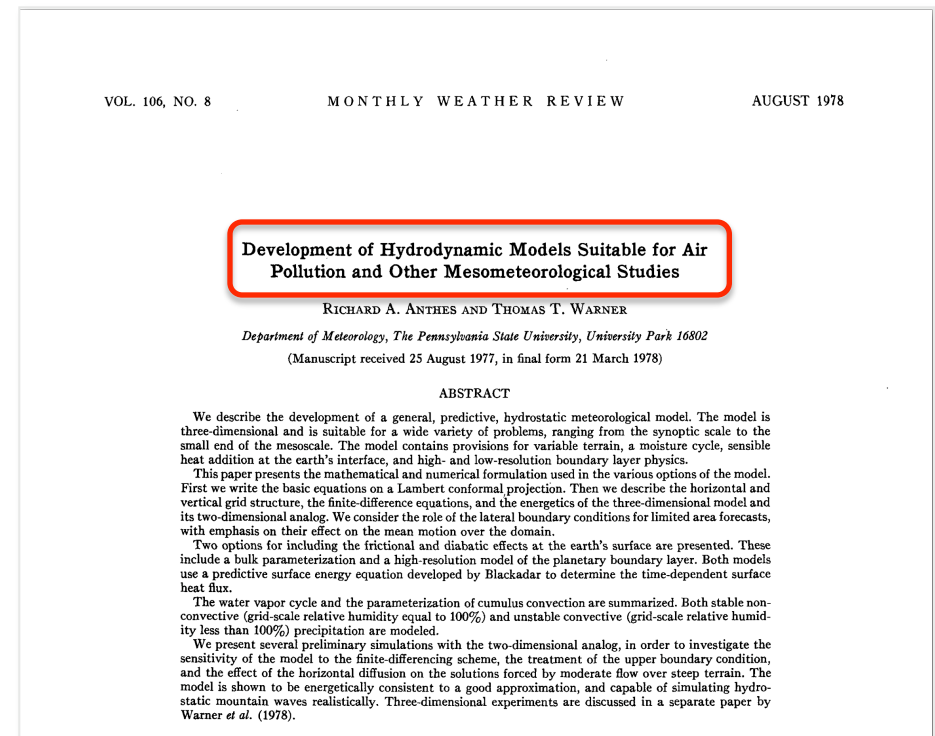
	UW	ECMWF	PNNL (CuP)
Trigger	Critical w , defined from CIN	Extreme test parcel (w)	Parcel θ_v
Closure (M_{CB})	Distribution of w , TKE	Depth of transition layer, depth of cloud layer, distribution of w	Distribution of parcel θ_v , TKE, convective time period, cloud-base height

Cloud Fraction 

- ▶ All closures have some relation to w
 - Parcel θ_v and w are related (e.g. CAPE)
 - While all three use the distribution of variables within the grid box, only PNNL (CuP) scheme tracks the entire family of parcels

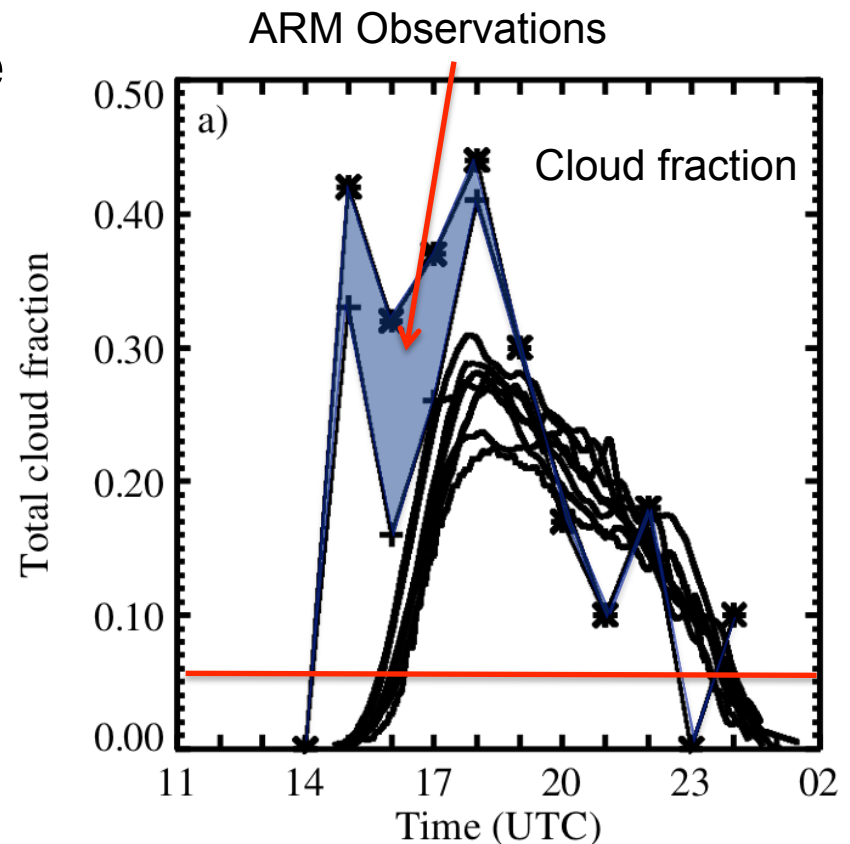
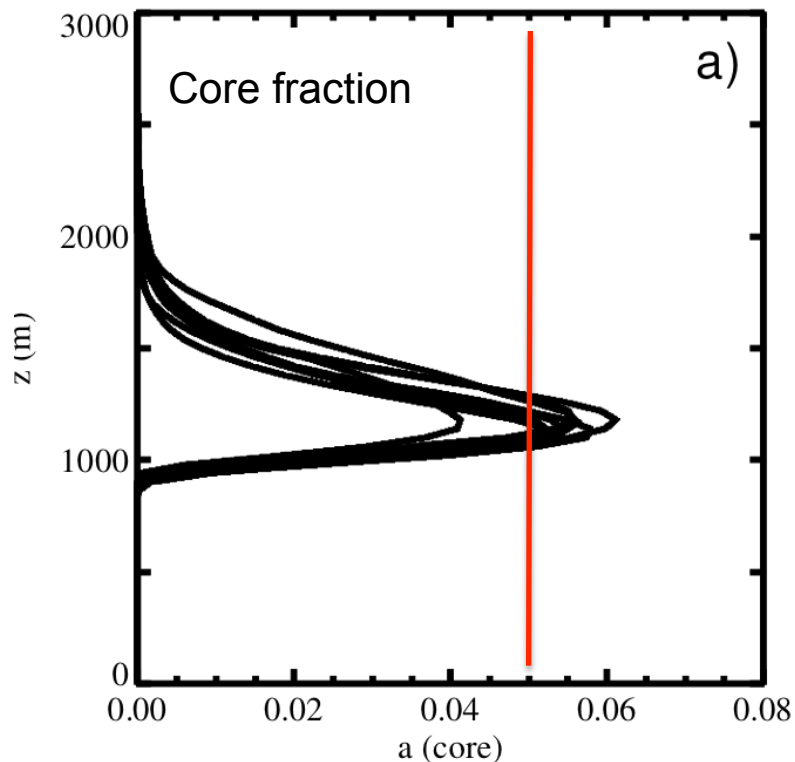
II. Parameterization of Cloud Fraction

- ▶ Historically, treatment of mass flux is treated independently of the cloud fraction
 - From the mesoscale forecast point of view the mass transport is important
 - Cloud fraction less important for short-term forecasts
- ▶ Are mass flux and cloud fraction the the same thing?



II. Cloud mass flux vs. cloud fraction

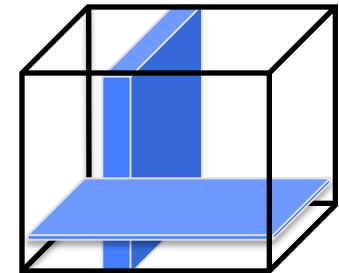
- **Cloud mass flux:** Transport due to updrafts



- **Cloud fraction:** lifetime of clouds

II. Param. of Cloud Fraction (in WRF)

- ▶ Parameterization of cloud fraction is done outside of the cumulus parameterization
 - Based on the radiation parameterization
 - Cloud water, cloud ice... things predicted in microphysics parameterization
 - Shallow Cu cloud water tends to be very small, clouds are mixed out in the microphysics parameterization
- ▶ *Clouds predicted by cumulus scheme but not seen by the radiation parameterization!*
- ▶ Solution: use the maximum of the radiation based cloud fraction or the cumulus cloud fraction



III. Sample Results: CuP & ACRF SGP Site

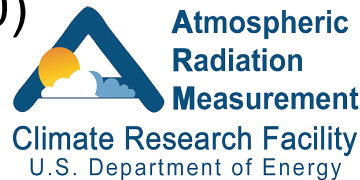
► Focused on CuP scheme

- Scheme has been implemented in WRF
- A set of simulations have been completed for the summer of 2004.

► Control simulations use Kain Fritsch scheme (KF-Standard)

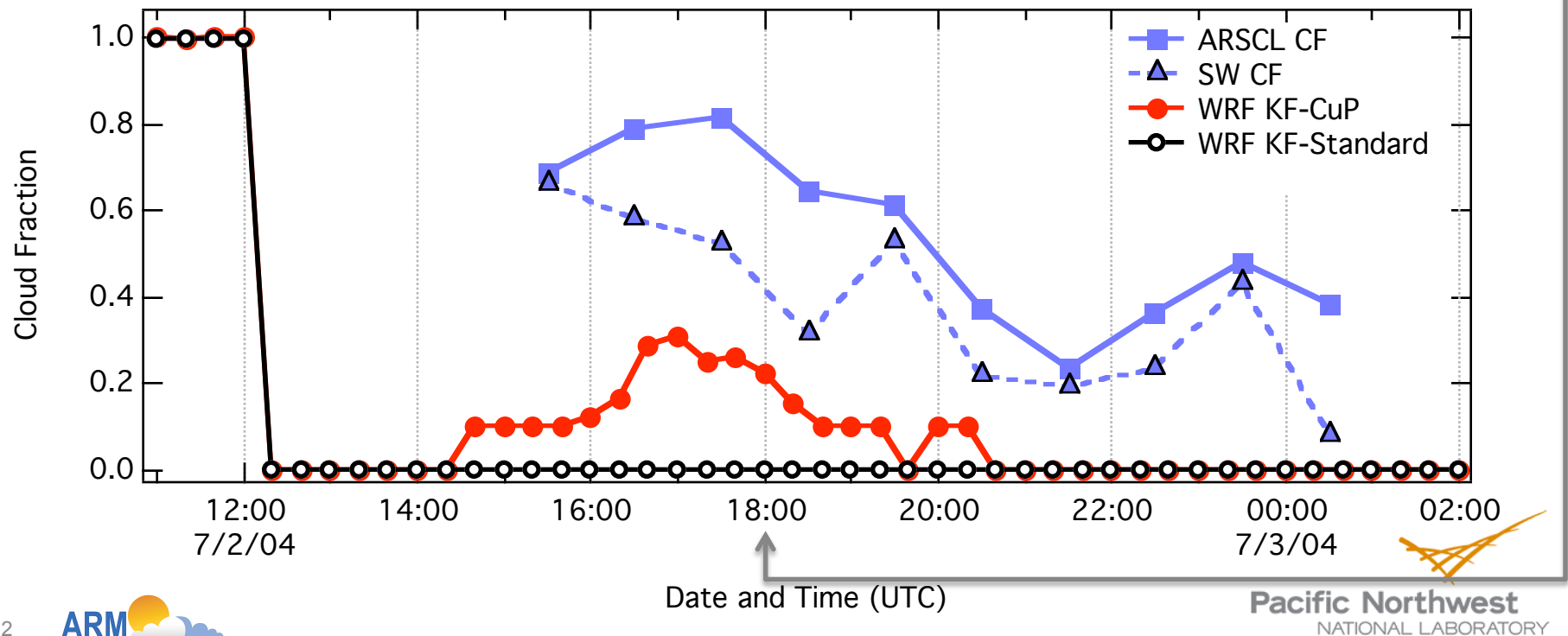
► Data

- ARSCL (Clothiaux et al. 2000)
 - Cloud boundaries
- Surface Cloud Grid VAP (SfcCldGrid; Long and Ackerman 2000)
 - Gridded ($0.25^\circ \times 0.25^\circ$) surface flux over the site
 - An attempt to move beyond the infamous soda straw



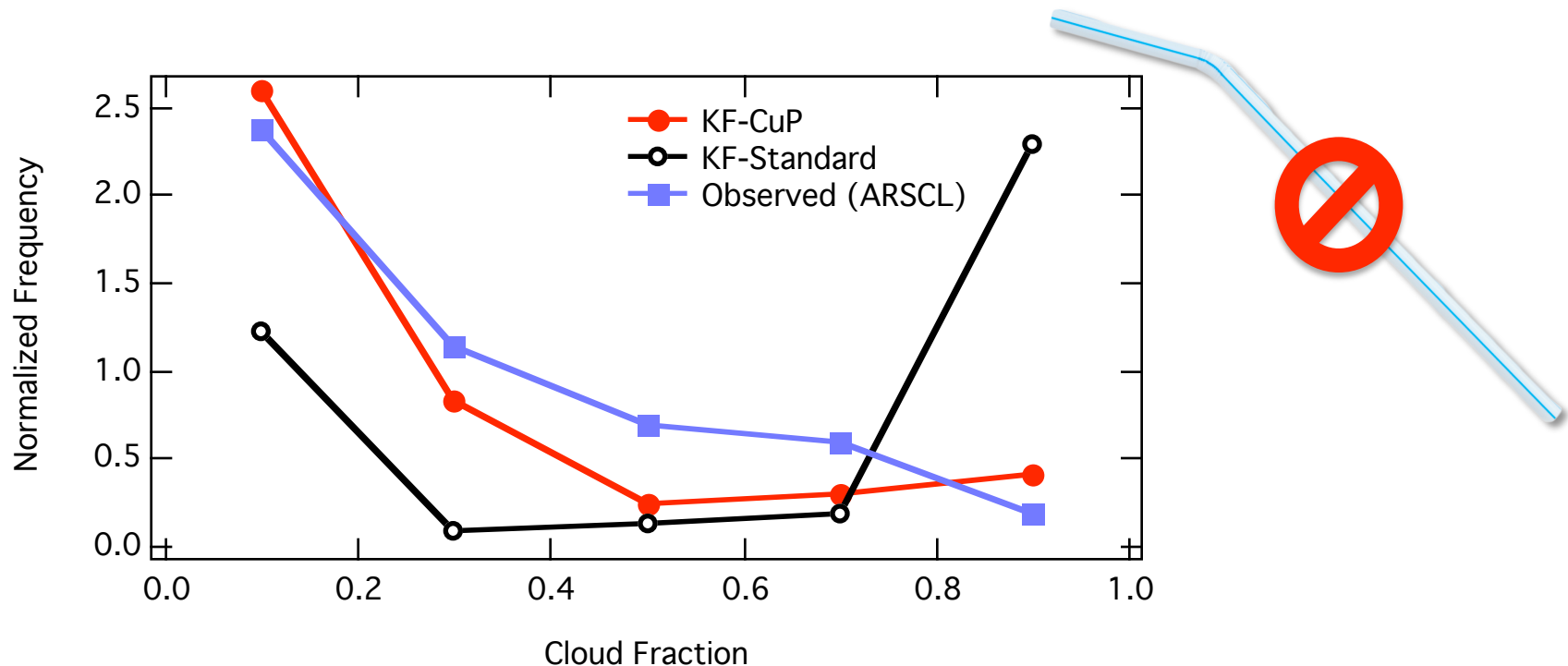
III. Case Study: Cloud Fraction

- ▶ Clouds predicted with KF-CuP, none with standard scheme
 - Cloud fraction is too small
 - Number of different ways to measure CF



III. Seasonal Simulations: Summer 2004

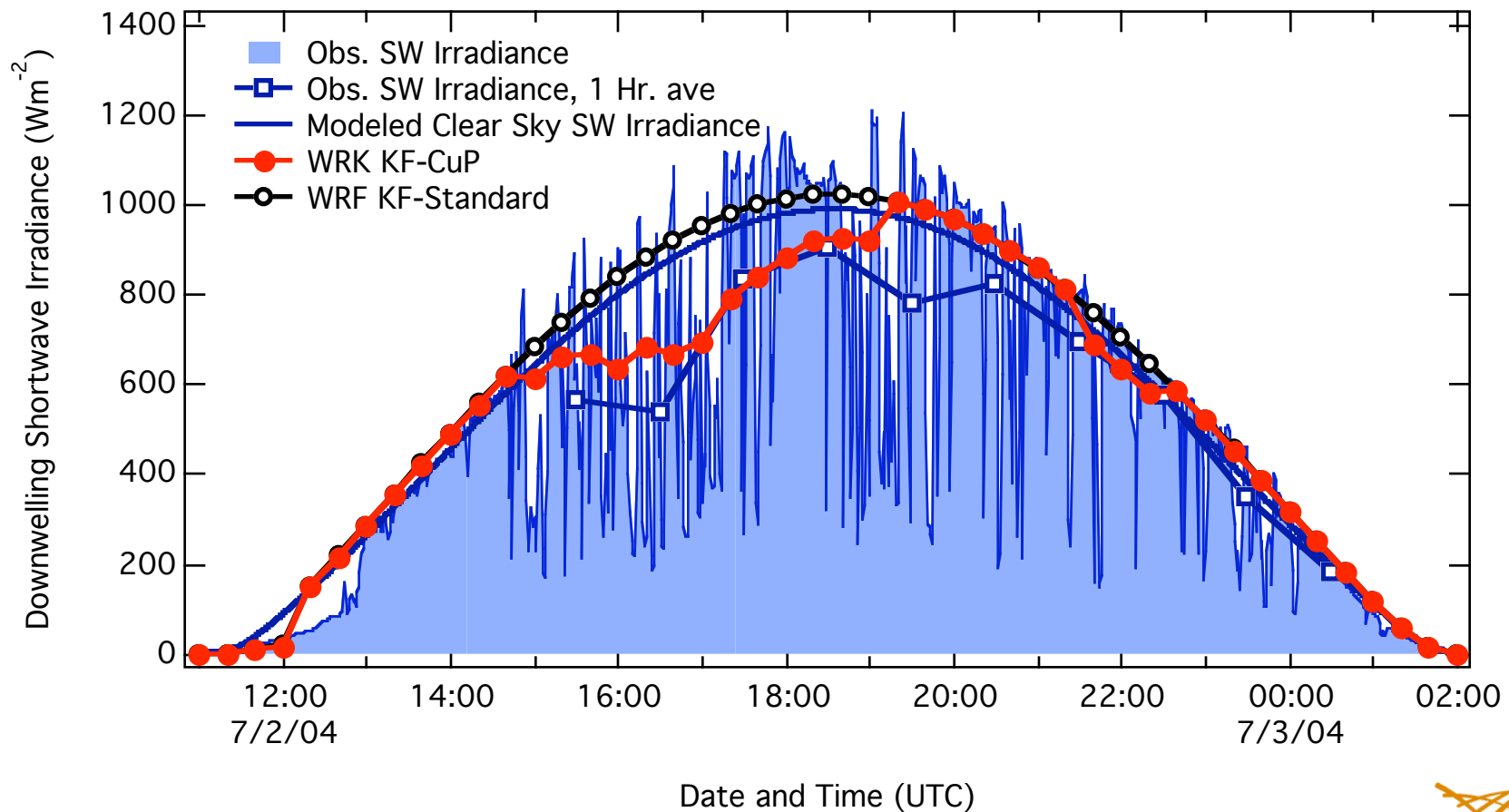
- ▶ KF-CuP does a better job predicting cloud fraction
 - Default predicts few clouds or nearly overcast
 - Some artifacts of minimum cloud amount



One way to move beyond the straw... time average

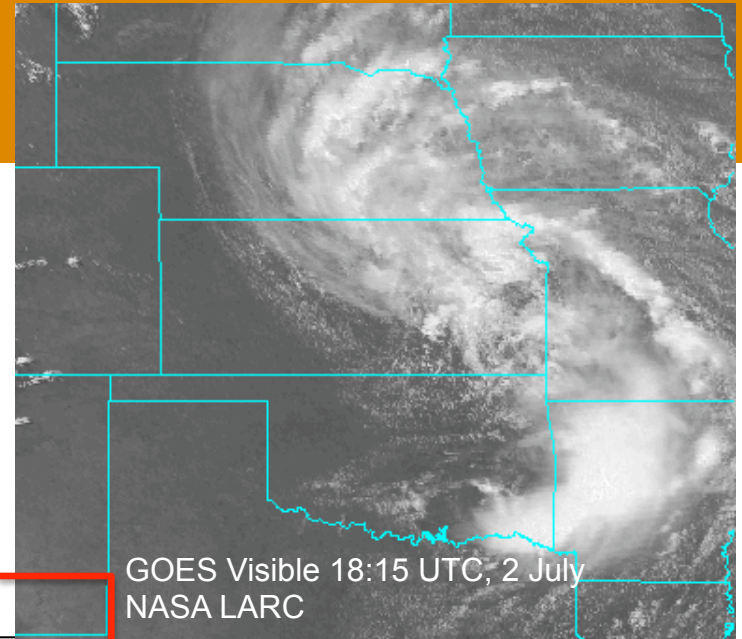
III. Case Study: Downwelling Shortwave

- Standard scheme underpredicts change in downwelling SW

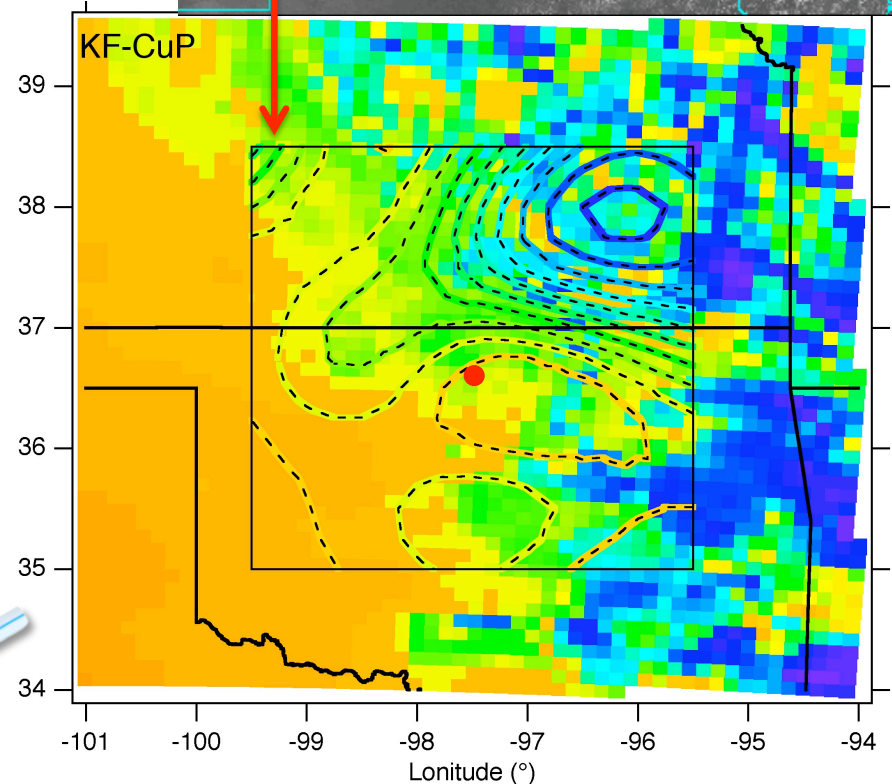
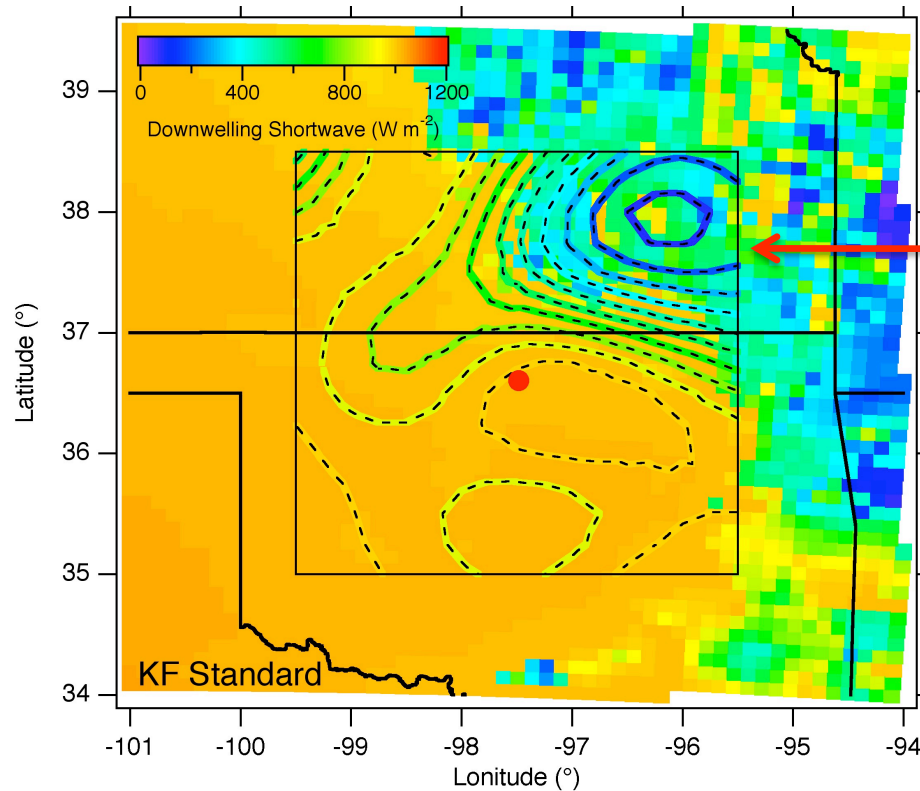


III. Downwelling SW

- ▶ More reduction of downwelling SW with KF-CuP



SfcCldGrid

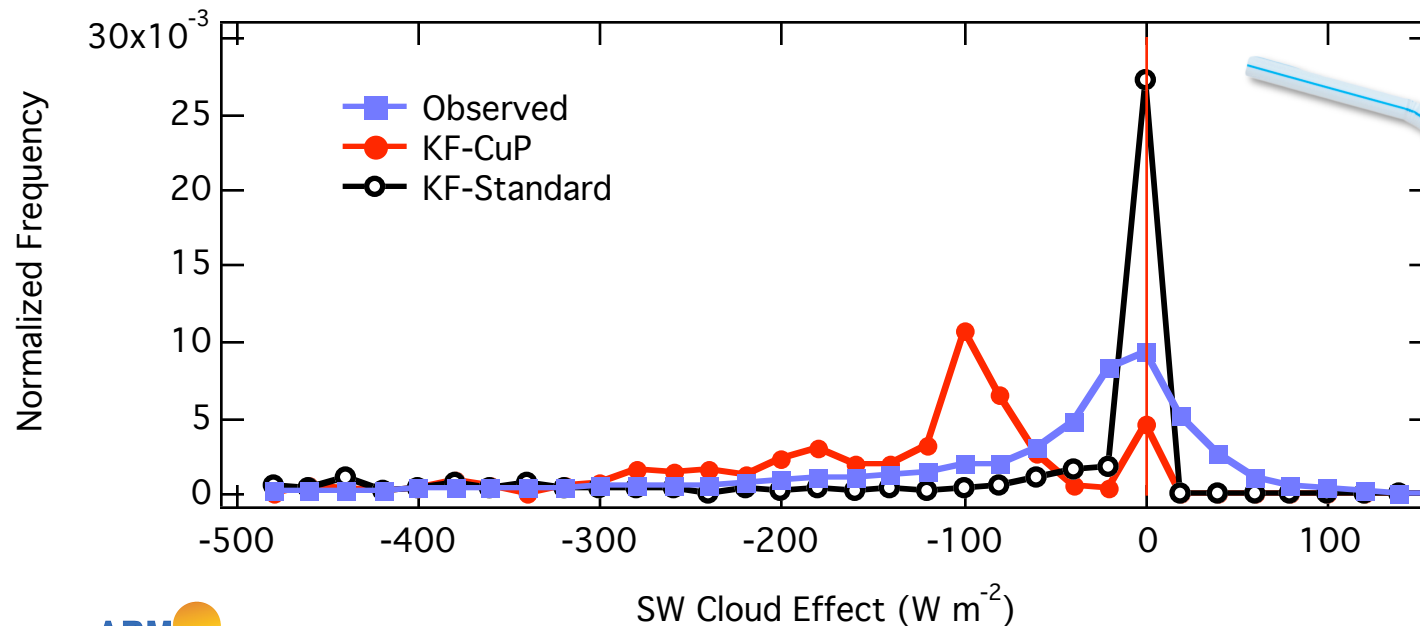


- ▶ Cloud predictions are sensitive to many parameters



III. Seasonal Simulation: Summer 2004

- Distributions of SW Cloud Effect (radiation time step of 10 m.)
 - KF has large peak at 0
 - KF-CuP has peak near -100 Wm^{-2}
 - Observations (15 minute average) peak near 0, and have cases with positive forcing



VI. Roadmap, Where Should We be Going?

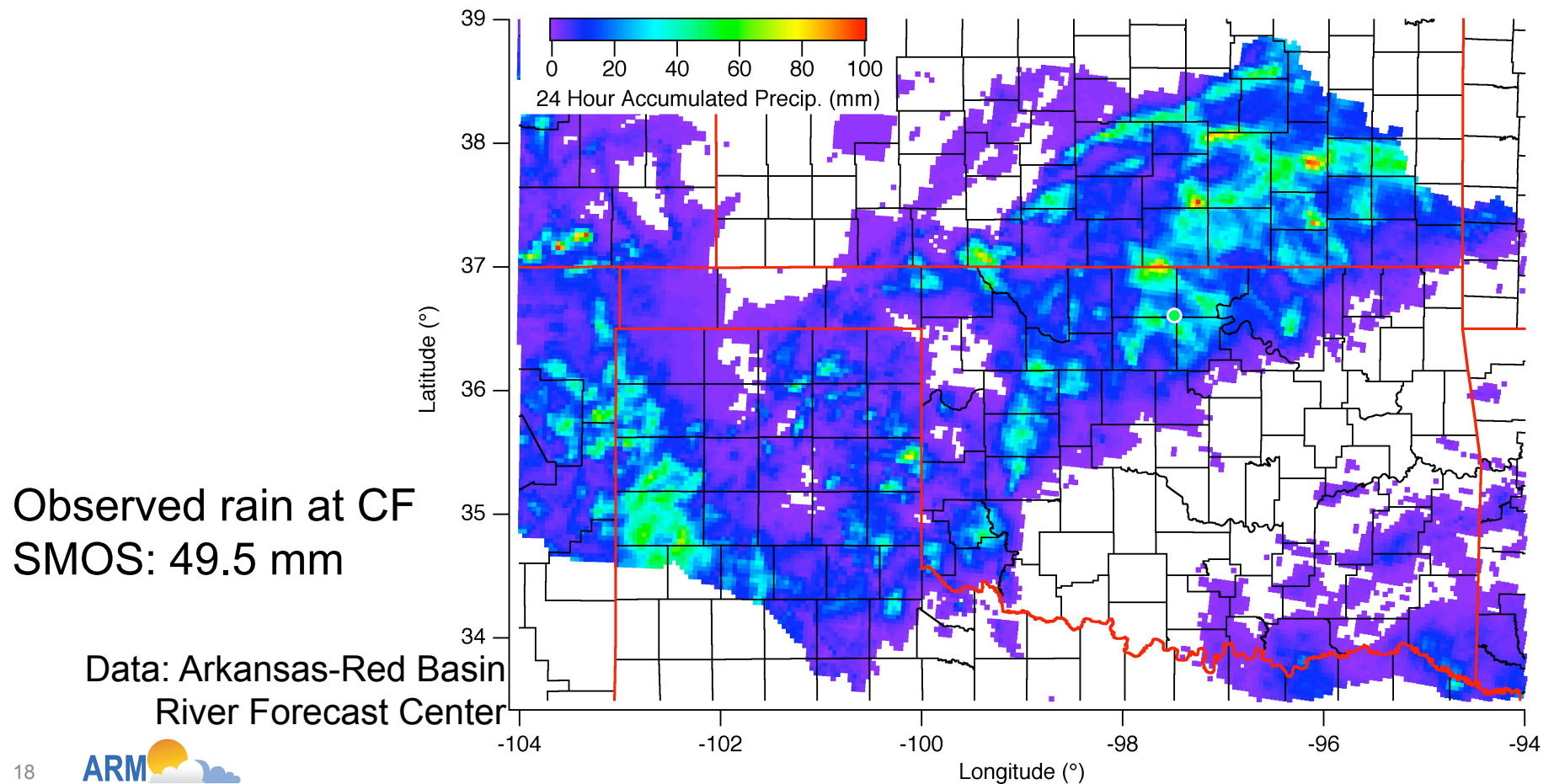
- ▶ Improved representation of the transition from shallow to deep convection
- ▶ Treatment of 3D radiative transfer
- ▶ Improved treatment of cloud-aerosol interactions
- ▶ Parameterization of shallow clouds in “cloud resolving” simulations
- ▶ Unified parameterizations, linking the boundary layer, shallow convection and deep convection
- ▶ Utilization of new data streams

All of ASR



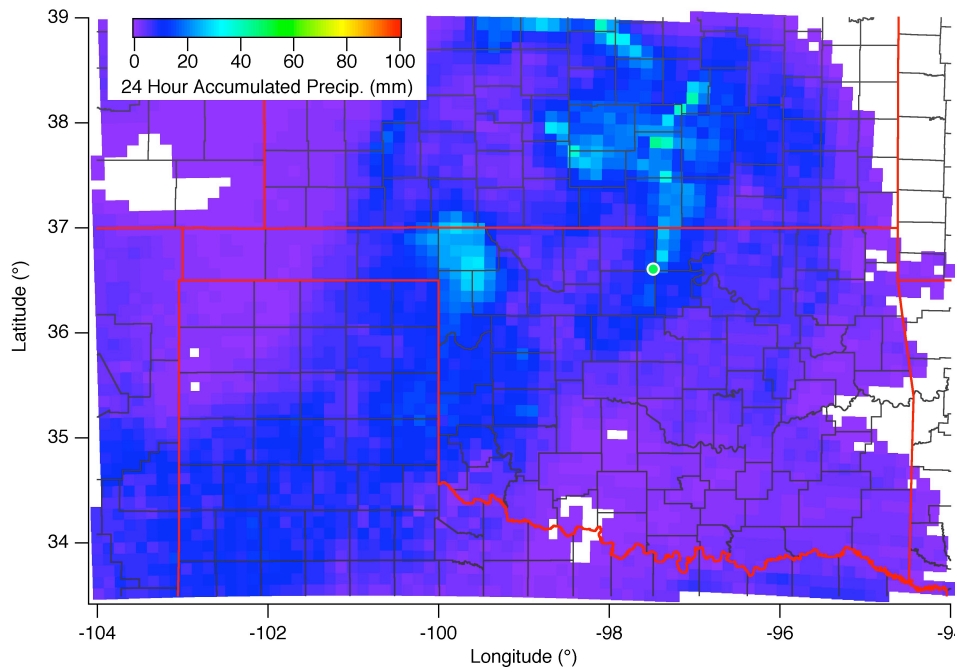
VI. Transition from Shallow to Deep Convection

- ▶ Better treatment of shallow clouds could improve forecasts of deep convection
- ▶ June 27-28 case, scattered thunderstorms

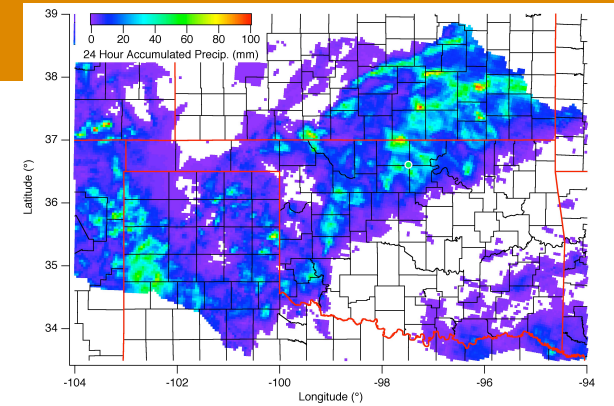


VI. Transition Cont:

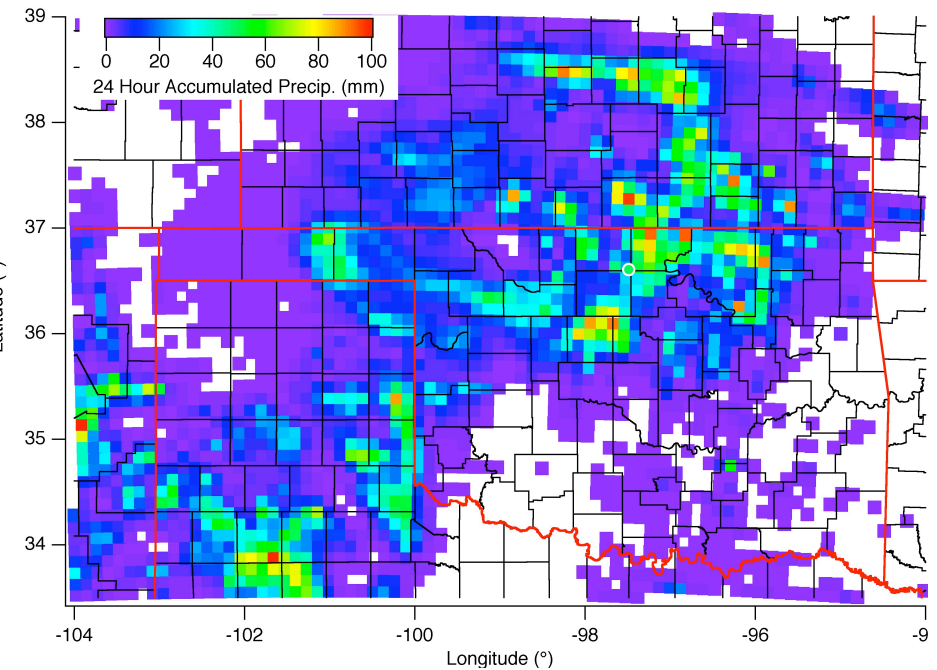
- Larger amounts of precipitation and less homogeneous with KF-CuP



KF-Standard



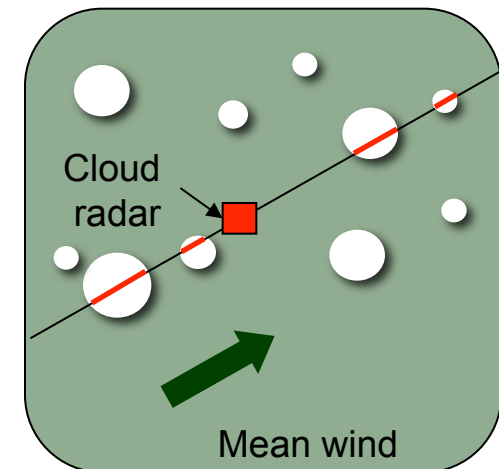
KF-CuP



VI. Treatment in Cloud Resolving Models

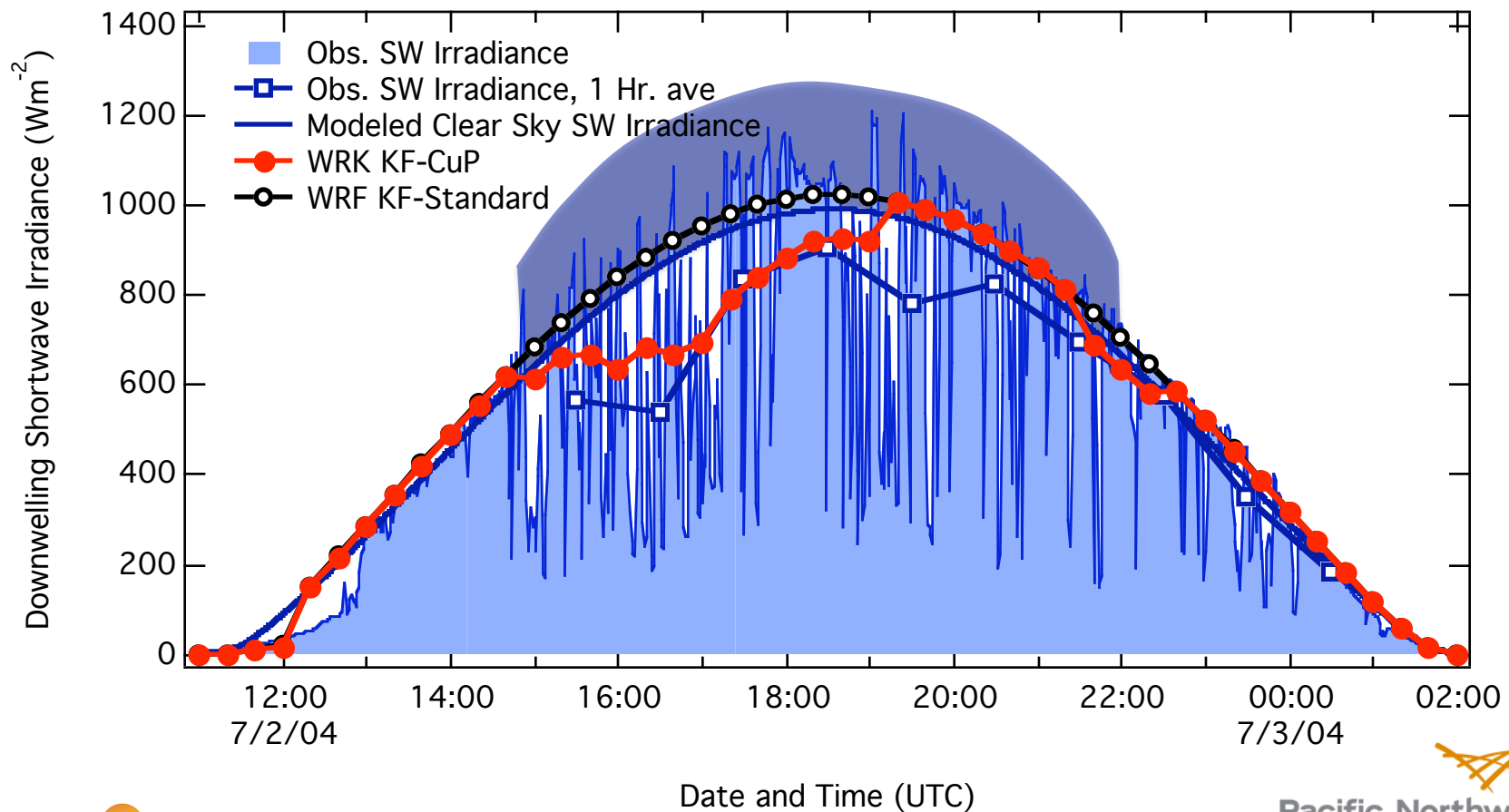
- ▶ Cloud scale resolving models use horizontal grid resolutions of 4, 2, or 1 km
- ▶ Spatial scale of shallow clouds is on the order of 1 km
 - Cloud chord length was found to be ~ 1 km

- ▶ $2\Delta x$ wave is best case
 - In practice WRF is close to $7\Delta x$ wave (Skamarock 2004)
- ▶ Parameterizations of shallow cumuli will be required for some time into the future

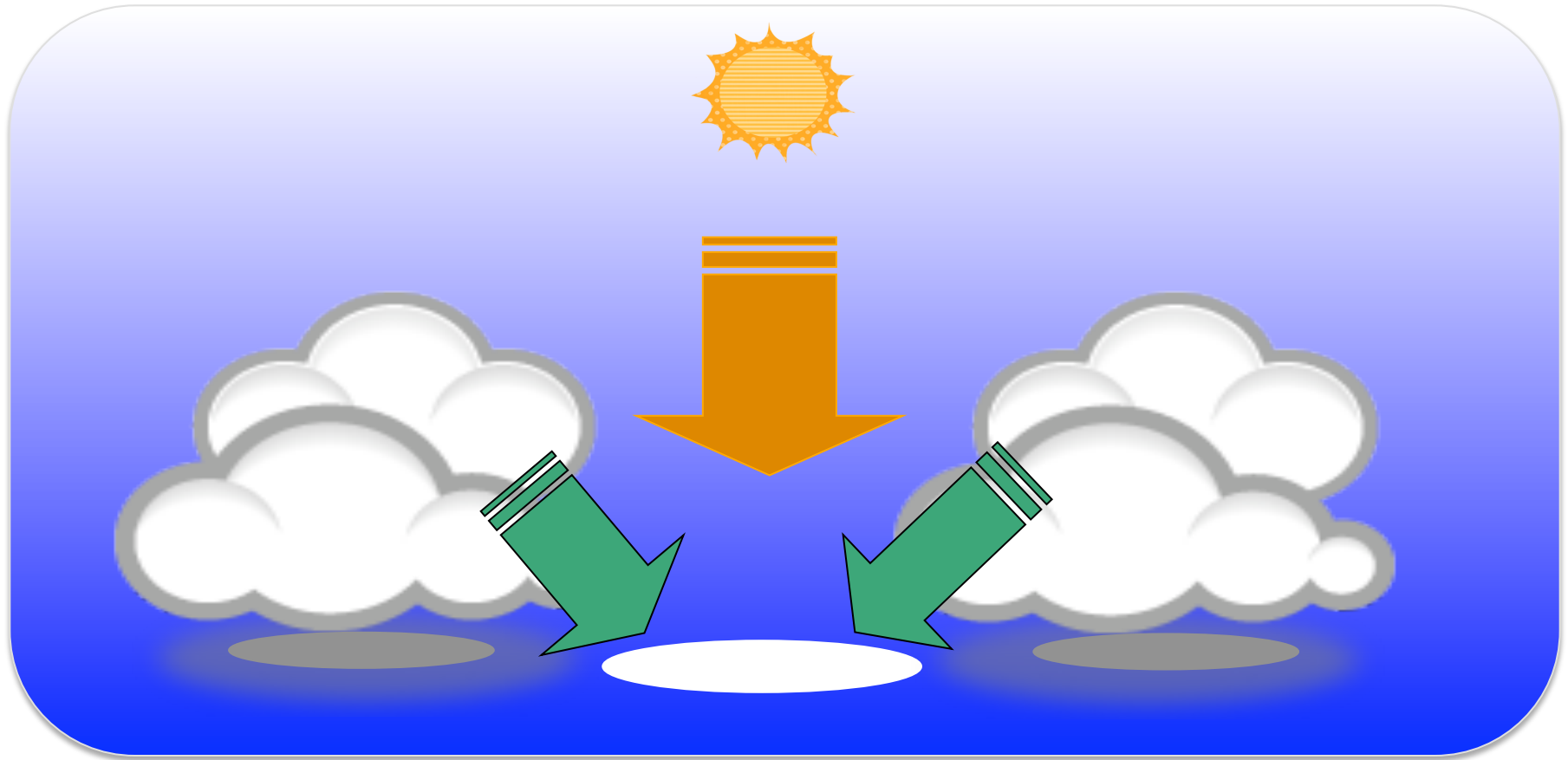


VI. Review: Downwelling Shortwave

- Many periods during which cloud effect is positive



VI. 3-D Impacts



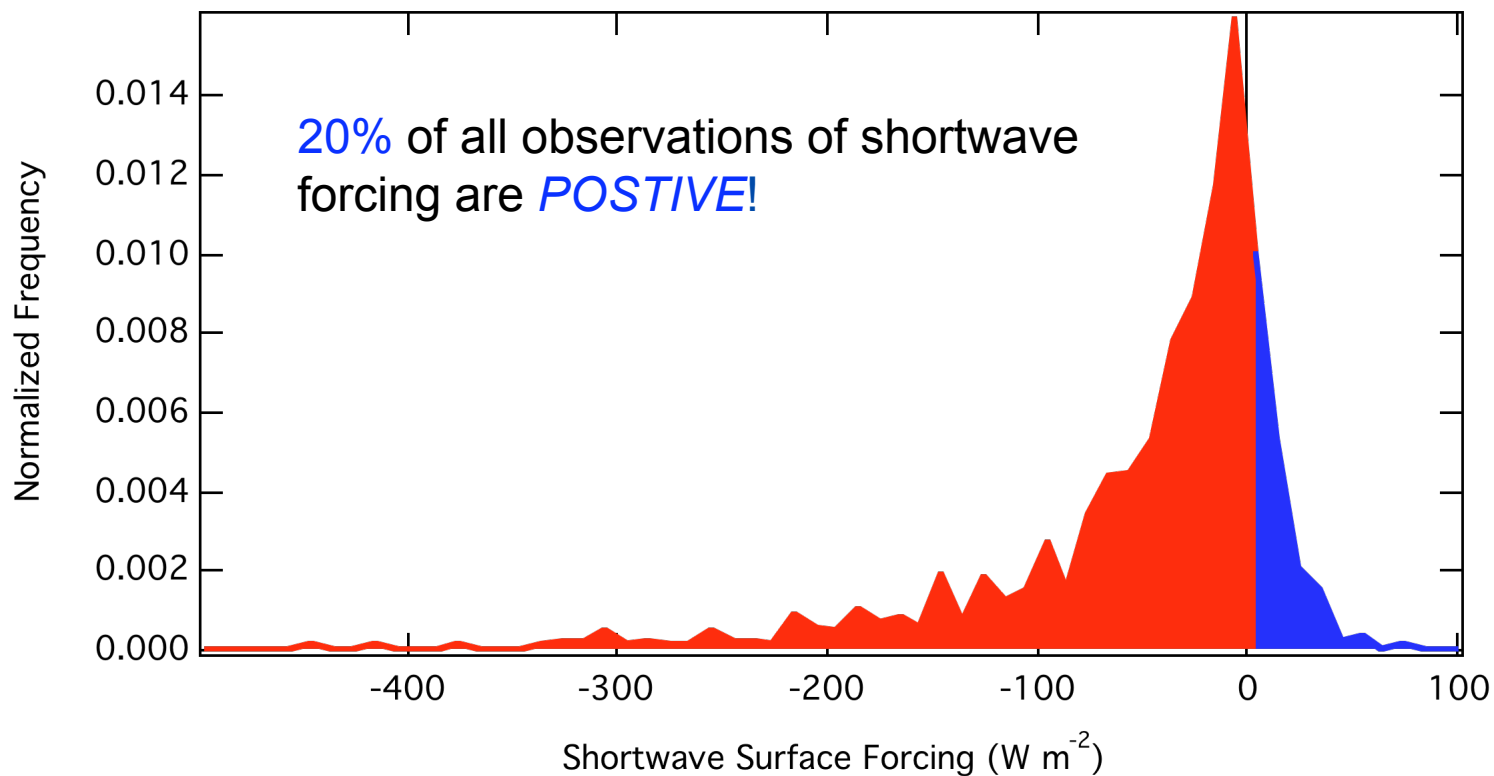
Total = Direct + Diffuse

Unblocked Direct (cloudy sky) = Direct (clear sky)

Diffuse (cloudy sky) > Diffuse (clear sky)

VI. 3-D Impacts

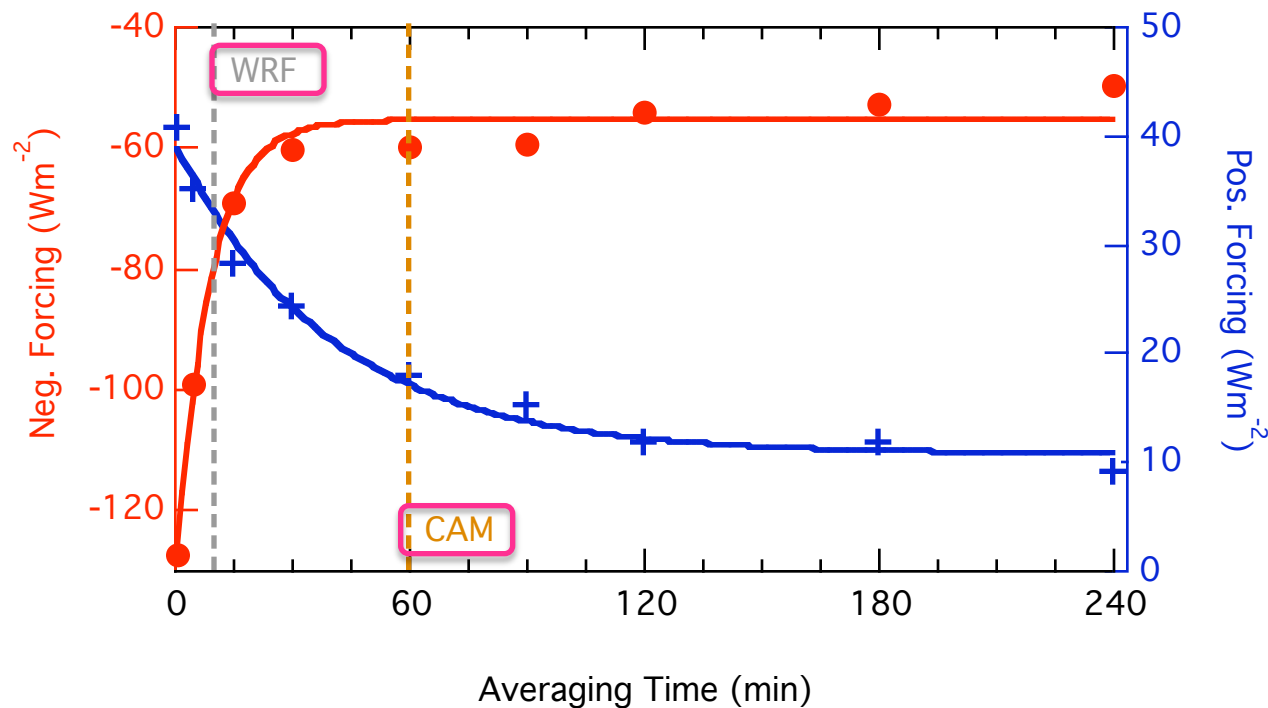
- Fields of shallow clouds are not homogeneous
 - Potential impact of 3-D cloud fields



Hourly average, summers of 2000-2007

VI. 3-D Impacts

- Instances of positive forcing even for large averaging times
 - At WRF time scales $\sim 30 \text{ Wm}^{-2}$
 - At CAM time scales $\sim 15 \text{ Wm}^{-2}$



Positive and negative forcing for moderate
(0.2-0.5) cloud cover

V. Conclusions

- ▶ Shallow Cu play an important role in climate and should not be ignored
- ▶ Regional scale models should be evaluated over long time periods
- ▶ New parameterizations have been developed that show improved predictions of cloud fraction and downwelling shortwave irradiance
- ▶ Where should we be going...
 - Transition from shallow to deep convection
 - 3D radiation
 - Parameterization of shallow clouds in high resolution models
 - Cloud-aerosol interactions
 - Unified parameterization



Conclusions

- ▶ Shallow Cu play an important role in climate and should not be ignored
- ▶ Regional scale models should be evaluated over long time periods
- ▶ New parameterizations have been developed that show improved predictions of cloud fraction and downwelling shortwave irradiance
- ▶ Where should we be going...
 - ❑ Transition from shallow to deep convection
 - ❑ 3D radiation
 - ❑ Cloud-aerosol interactions
 - ❑ Unified parameterization
 - ❑ Parameterization of shallow clouds in high resolution models



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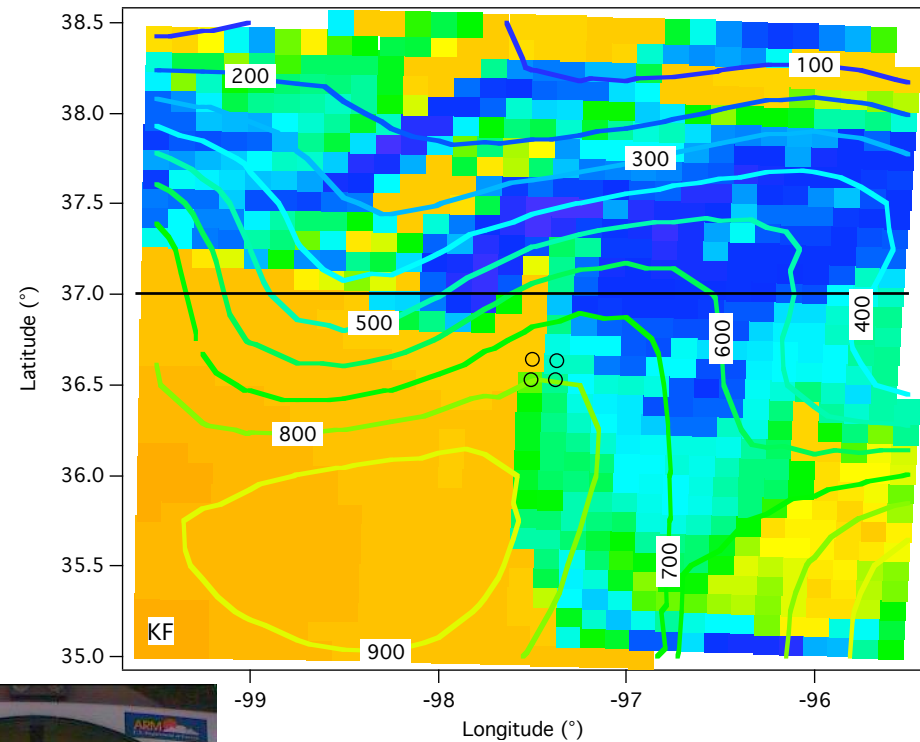
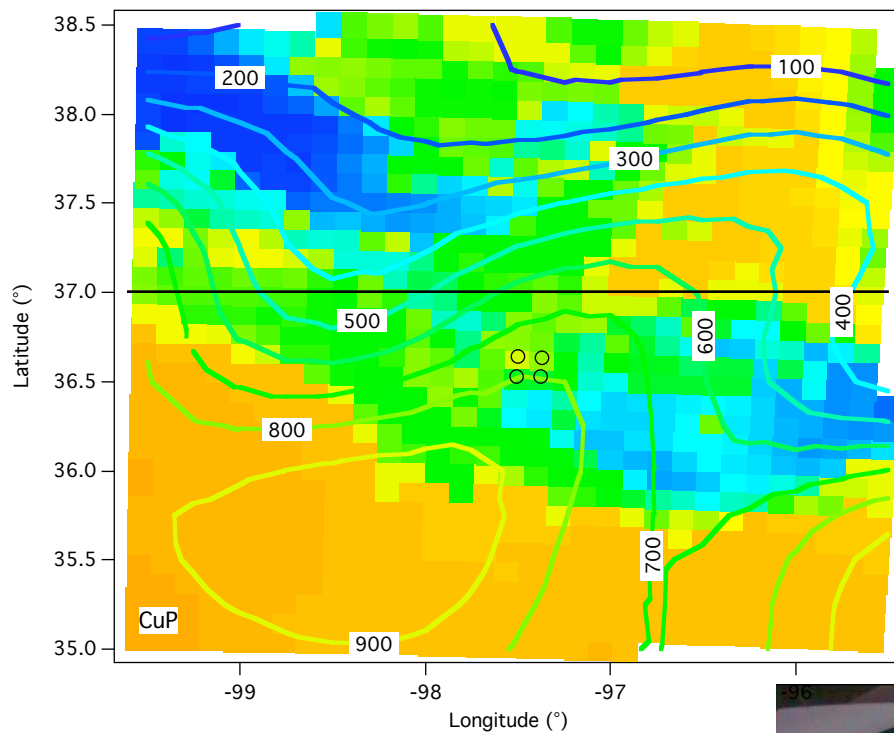


Outline



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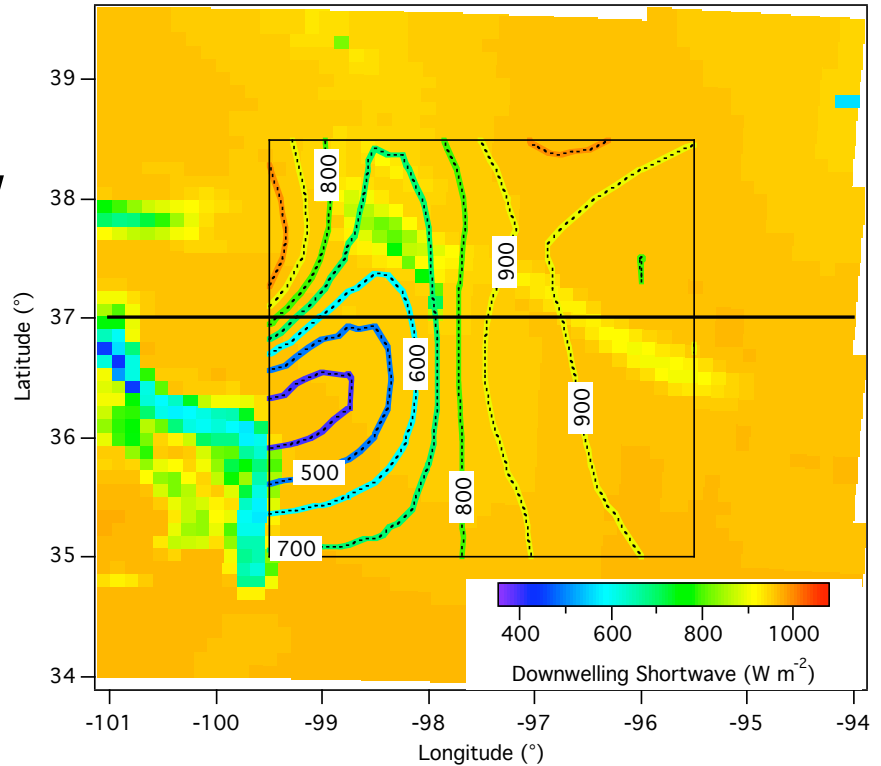
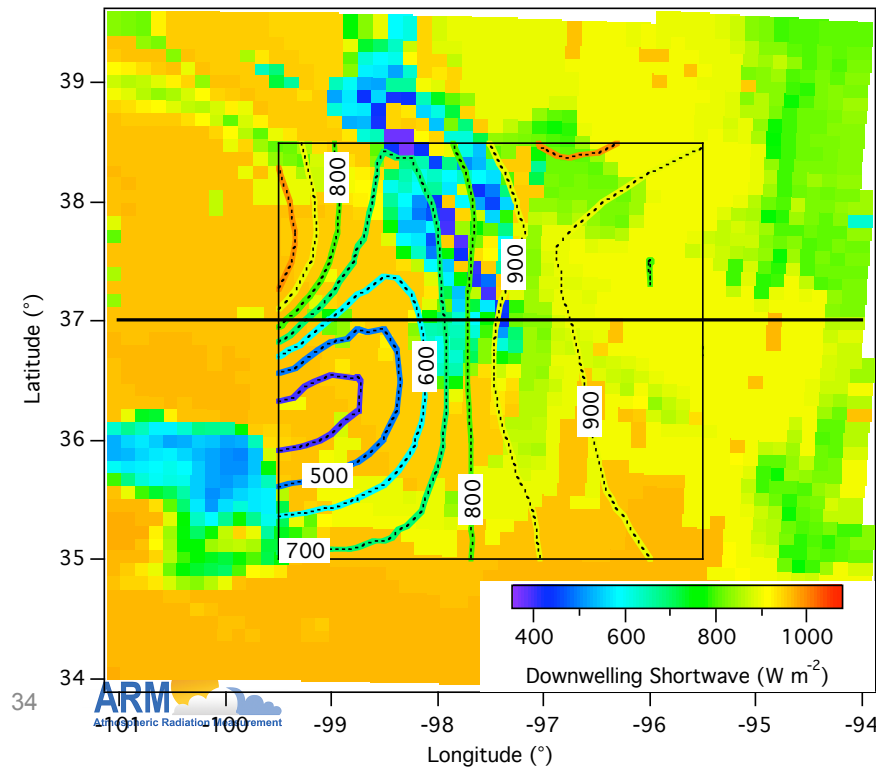
Case Study: May 18, 2004



Case Study 17 July

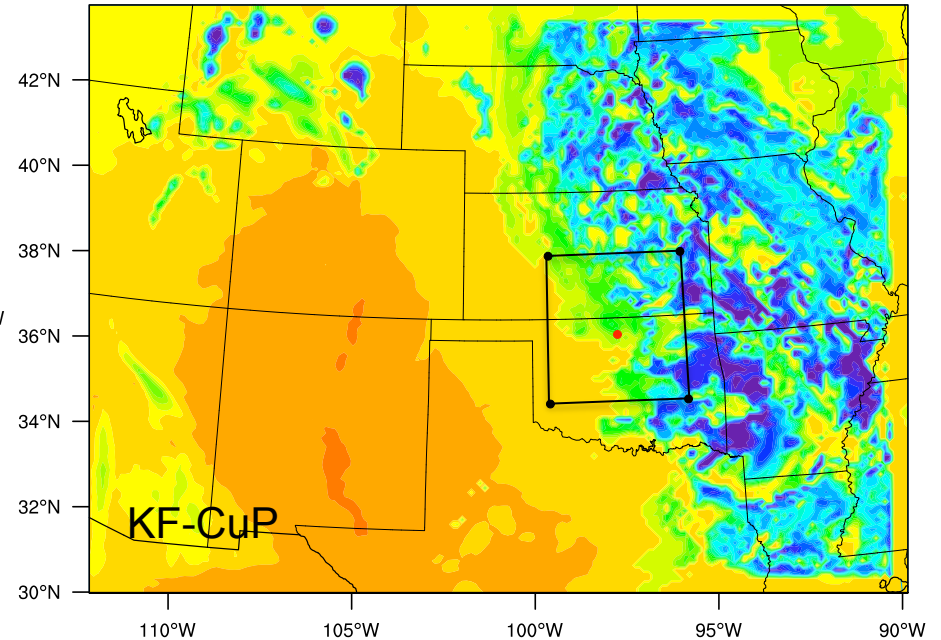
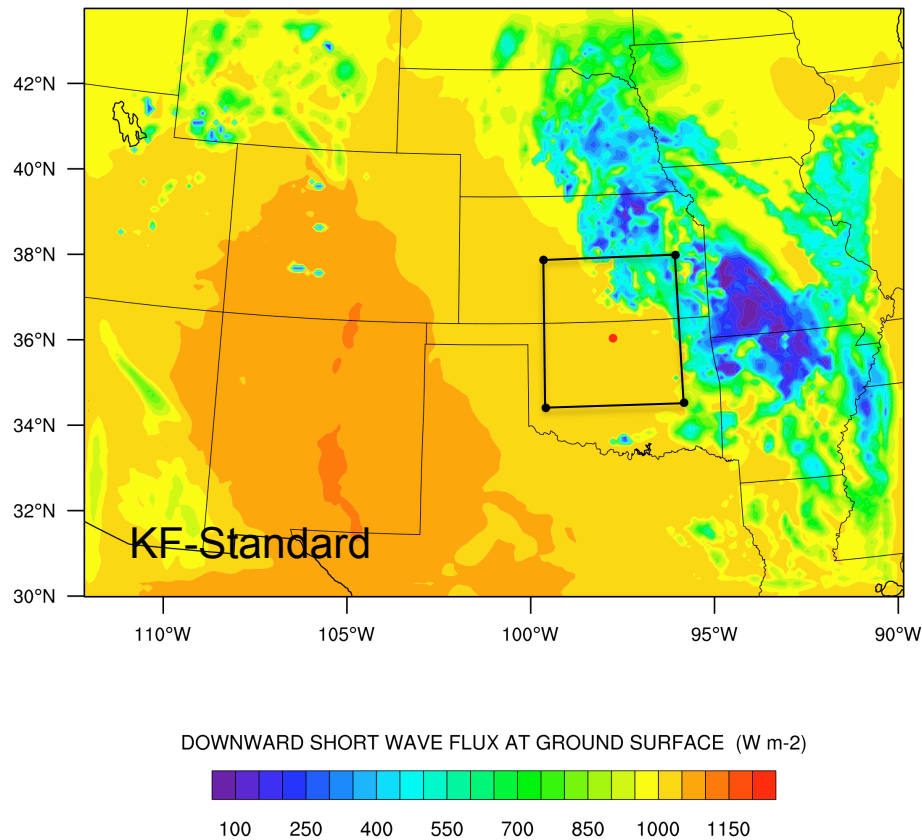
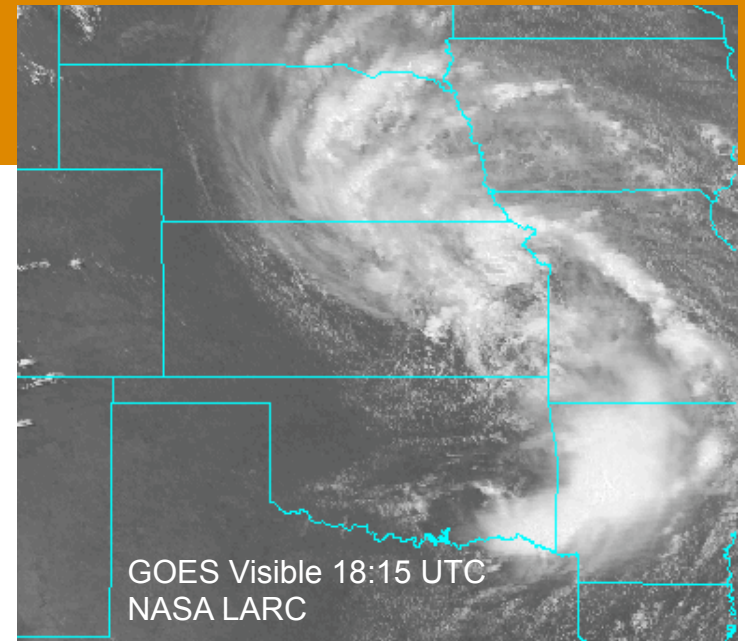
► Results shown for 19 UTC, on 17 July 2004

- Contours SWCLDGRD
- Colors WRF Downwelling SW



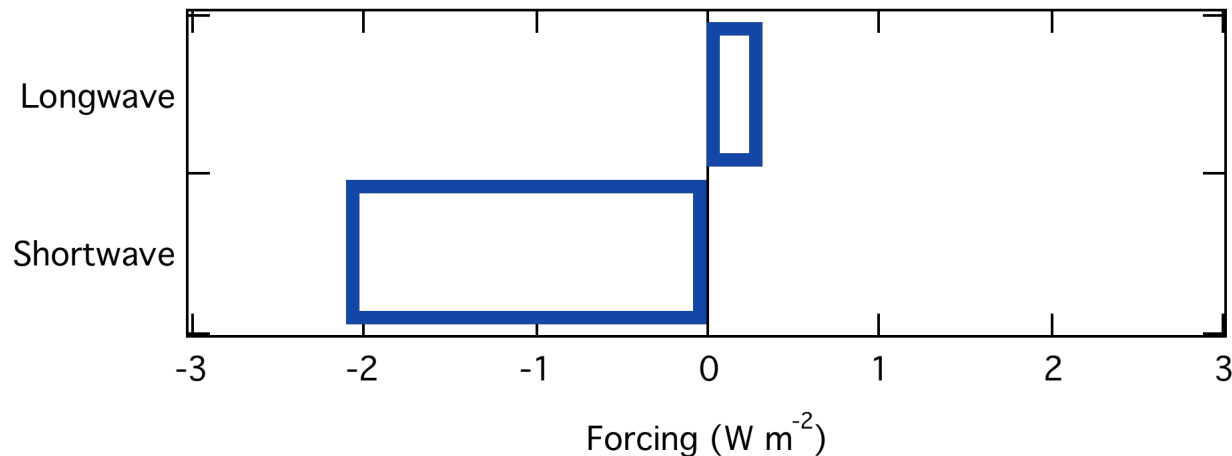
III. Case Study: July 2

- Large differences over Iowa and Missouri



I. Why Shallow Clouds: Radiation

- ▶ Recent study (Berg et al. 2009) has looked at the shortwave and longwave cloud forcing
 - Makes use of Chuck Long's VAPs that make estimates of clear-sky shortwave and longwave fluxes
 - When all times (both clear and cloudy) are considered shortwave and longwave forcing are small



Can be eliminated in model tuning

Model setup

- ▶ Single domain
 - 182 x 131 x 45
- ▶ Parameterizations
 - WRF Single Moment (WSM) 6-class microphysics
 - CAM shortwave and longwave
 - Mellor-Yamada-Janjic (ETA) boundary layer
 - NOAH surface layer
- ▶ Boundary conditions from North American Regional Reanalysis (NARR)